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RESEARCH DEPARTMENT REPORT

A receiver for measuring the radiated harmonics of u.h.f. television transmissions

No. 1969/2

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

RESEARCH DEPARTMENT

A RECEIVER FOR MEASURING THE RADIATED HARMONICS OF U.H.F. TELEVISION TRANSMISSIONS

Research Department Report No. 1969/2
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(RA-29)

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A RECEIVER FOR MEASURING THE RADIATED HARMONICS OF U.H.F. TELEVISION TRANSMISSIONS

SUMMARY

This report describes a receiver which, as part of the work to assess possible interference to radio astronomy arising from Band IV/V television stations, was developed for measuring low-level harmonic radiation in the frequency range 1 to 2 GHz. The receiver employs a simple commutator detector which, with the fundamental signal square-wave modulated, enables input signals of about 0·5 μV to be measured. The complete receiving equipment (including a horn aerial) enables harmonic field strengths of about 8 dB (μV/m) to be measured, in the presence of fundamental field strengths up to about 120 dB (μV/m).

The complete equipment is readily transportable, it can easily be tuned over the frequency band and it is simple to operate. The report discusses features of the design which could be changed if the sensitivity needs to be further improved, but, as the report points out, this can only be achieved at the expense of simplicity and versatility.

1. INTRODUCTION

At all transmitting stations, it is important to ensure that no out-of-band radiation exceeds a level which could cause interference to other radio services. The maximum permissible level of such radiation from u.h.f. television stations is not at present fully specified in precise terms but equipment is normally installed which ensures that no individual out-of-band spectral component exceeds −60 dB relative to peak sync power. This limit is found to be generally acceptable but there are exceptions, the most important of which applies when the radiation occurs in a radio-astronomy band. In these parts of the radio spectrum the out-of-band radiation may require to be reduced to a much lower level.

The only radio-astronomy bands considered in this report are those containing the hydrogen and hydroxyl (OH) 'line' emissions. Although these line emissions occur only at specific frequencies, it is necessary to provide bands of frequencies for measurement purposes in order to allow for Doppler shift. The hydrogen-line band is generally defined as 1,400 to 1,427 MHz and, in that band, the Post Office in consultation with the radio astronomers have specified interference power equivalent to steady signals of −41 dB (μV/m) and −34 dB (μV/m) as being harmful at the radio observatories at Jodrell Bank and Cambridge respectively. The hydroxyl-line band is not so clearly defined but, for the purpose of this report, it is taken to be 1,645 to 1,675 MHz. Harmful levels of interference in this band have also not been clearly defined, but it is likely that they are of the same order as those in the H-line band. Bearing in mind that the peak sync field strength of u.h.f. television transmissions may exceed 70 dB (μV/m) at the radio observatories, it is clear that spurious emissions in these bands should ideally be suppressed below −100 dB relative to peak sync power.

Radiation arising from second and third harmonics of the carrier frequencies, and from intermodulation between the carriers, will occur in one or both of these two radio-astronomy bands at 49 of the 61 main u.h.f. television stations now being planned or implemented. It is reasonable to suppose that a similar proportion of relay stations could also cause interference in this way.

The question of interference to radio astronomy therefore constitutes an important factor when planning u.h.f. stations. It is possible to specify high-power filters which would provide adequate suppression but, first, the level at which the interfering signals are generated in the transmitters must be known because this determines the attenuation required. In addition, the level at which they may be regenerated in the aerials and feeders must be known because this determines the maximum amount of attenuation (and thus the maximum degree of suppression) that it is technically feasible to provide.

It was therefore desirable to attempt to measure low-level signals (e.g. 1 to 10 μV) in the frequency range 1 to 2 GHz, in the presence of high-level signals (e.g. 100 mV to 1 V) in Bands IV and V. Because no suitable receiver was commercially available, the receiver described in this report was developed. The results of measurements made on transmitters, and discussion of their implication, will form the subject of a separate report.

2. THE RECEIVER

2.1. General Description

The receiver* comprises an Air Ministry receiver type 1294, modified to improve its sensitivity and noise factor. This receiver has a cavity-tuned crystal mixer, without an r.f. stage, a 13·5 MHz i.f. amplifier with an overall bandwidth of 250 kHz, and an envelope detector followed by a two-stage video amplifier. Three modifications were made to the basic receiver:

(i) Because valves were no longer available for the original local oscillator, an external local oscillator was provided. Arrangements were made to monitor its frequency using a digital frequency counter.

(ii) A cascode i.f. pre-amplifier was installed to increase the i.f. gain and improve the noise factor.

(iii) A mixer-diode current meter was fitted; this was necessary as it was found that there was a restricted range of diode current (200 to 300 μA) within which the optimum noise performance was obtained.

The noise factor of the modified receiver is 5 dB at 1 GHz rising to 9 dB at 1·7 GHz (measured at optimum mixer-diode current). In this condition the open-circuit input signal from a 50 ohm source at room temperature which produces a signal output power equal to the noise output power is 1·6 μV at 1 GHz, increasing to 2·6 μV at 1·7 GHz.

2.2. Method of Detection

In order to improve further the overall sensitivity of the receiver without undue complication a commutator detector was provided subsequent to the envelope detector of the basic receiver. The principle of the commutator detector is as follows. The received signal is square-wave modulated at a low frequency; the output of the receiver envelope detector thus comprises a square wave with noise superimposed. This output is fed into the commutator detector together with a reference signal consisting of the (noise-free) square-wave modulation. The detector compares the receiver outputs during the two half-cycles of the reference signal and produces a d.c. output proportional to the difference between the two conditions.

It is possible to operate a very simple commutator detector working on this principle by square-wave modulating the signal incoming from the aerial, but this method has three rather serious drawbacks. Firstly, the modulator in the aerial feeder introduces loss. Secondly, the action of the modulator causes transients at the receiver input which are synchronous with the reference signal. The receiver therefore gives an output indication when no input signal is applied. Finally, it should be noted that the only noise which a system of this type can discriminate against is that which arises in the receiver; any interfering signals picked up by the aerial will be treated as wanted signal by the device.

In view of these drawbacks an alternative system was adopted whereby the transmitter was

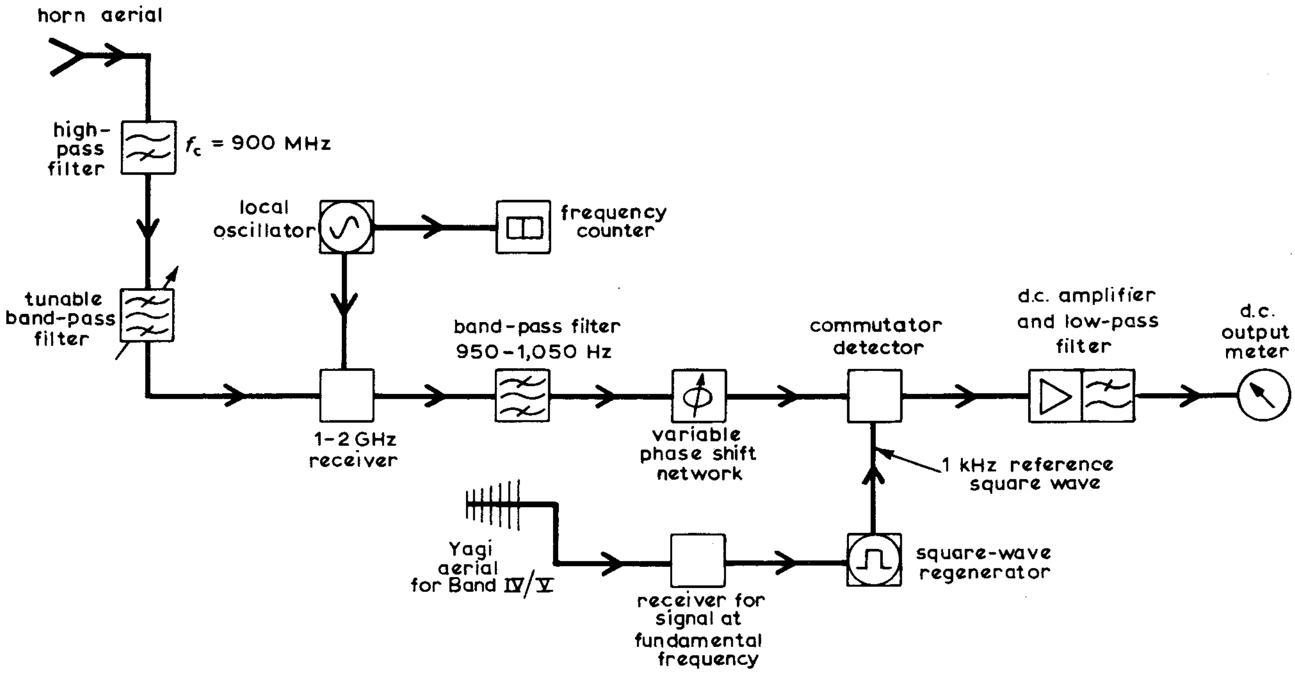
horn aerial
high-pass filter
f_c = 900 MHz
local oscillator
frequency counter
tunable band-pass filter
band-pass filter 950-1,050 Hz
commutator detector
d.c. amplifier and low-pass filter
d.c. output meter
1-2 GHz receiver
variable phase shift network
1 kHz reference square wave
Yagi aerial for Band IV/V
receiver for signal at fundamental frequency
square-wave regenerator

Fig. 1 - Block diagram of receiving system

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* The design and construction of the receiver was carried out largely by G.H. Millard and D.J.Neale.

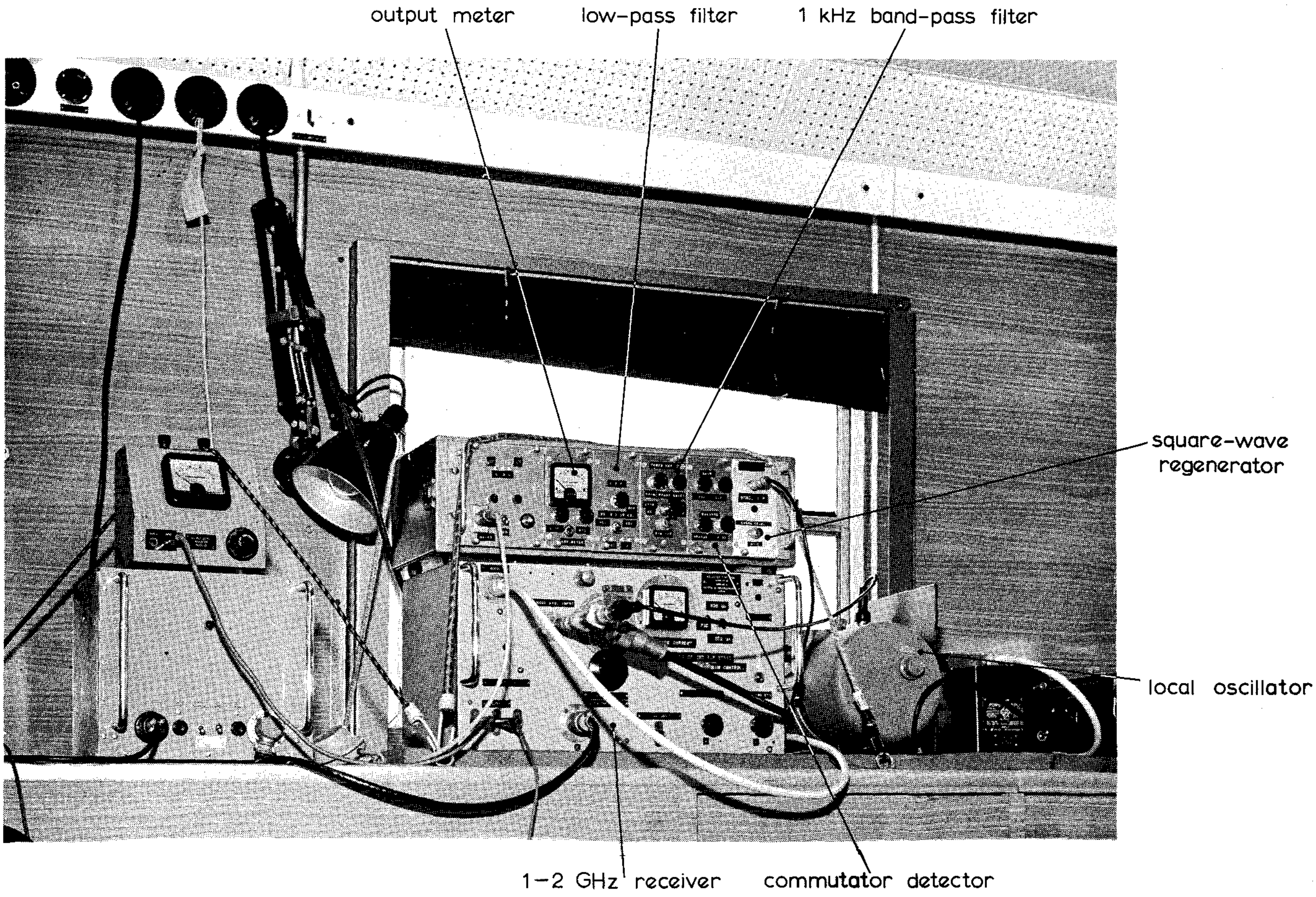

Fig. 2 - The receiver and commutator detector assembly

100% modulated by a 1 kHz square wave; a reference signal for synchronizing the commutator detector was derived from a separate receiver tuned to the fundamental signal whilst the measuring receiver was tuned to the required harmonic frequency. In order to provide a noise-free reference signal, the reference square wave was regenerated locally using a trigger circuit.

A block diagram of the complete system is shown in Fig. 1. High-pass filters in the aerial feeder prevented harmonic generation in the receiver from the high-level fundamental signal. The tunable bandpass filter also helped in this respect, but its prime function was to permit the identification of the received harmonic signal. The receiver was sufficiently well screened for it to operate satisfactorily in a high ambient fundamental field strength (but not sufficiently well for it to be used in transmitter buildings). The receiver output signal was fed to the commutator detector through a 1 kHz band-pass filter and a variable phase-shift network; the latter enabled the signal phase to be adjusted to give maximum sensitivity. The commutator detector consisted of a differential amplifier, using a pair of transistors; the signal output from the main receiver was fed co-phased to the two emitters, the reference signal driving the two bases in anti-phase. Thus the two transistors were alternately switched on and off by the reference signal synchronously with the modulation on the received signal. Outputs were taken from the two collectors to a d.c. differential amplifier driving a d.c. output meter via a low-pass filter.

Under no-signal conditions, there is no deflection of the output meter since the square waves at the two collectors of the commutator detector are equal in amplitude. When a synchronous signal is present, however, an unbalance occurs which causes a reading on the meter. Residual noise fluctuations are largely removed by the low-pass filter which should, ideally, have a long time-constant. In practice the time-constant that could be usefully employed was limited by drift in the d.c. amplifier.

For use, the complete equipment was mounted in a mobile laboratory as shown in Fig. 2. Fig. 3 shows the arrangement of aerials on the vehicle. The small dish aerial was used to radiate a low-level signal to test the equipment since, in many cases, the harmonic signal to be measured was immeasurably small.

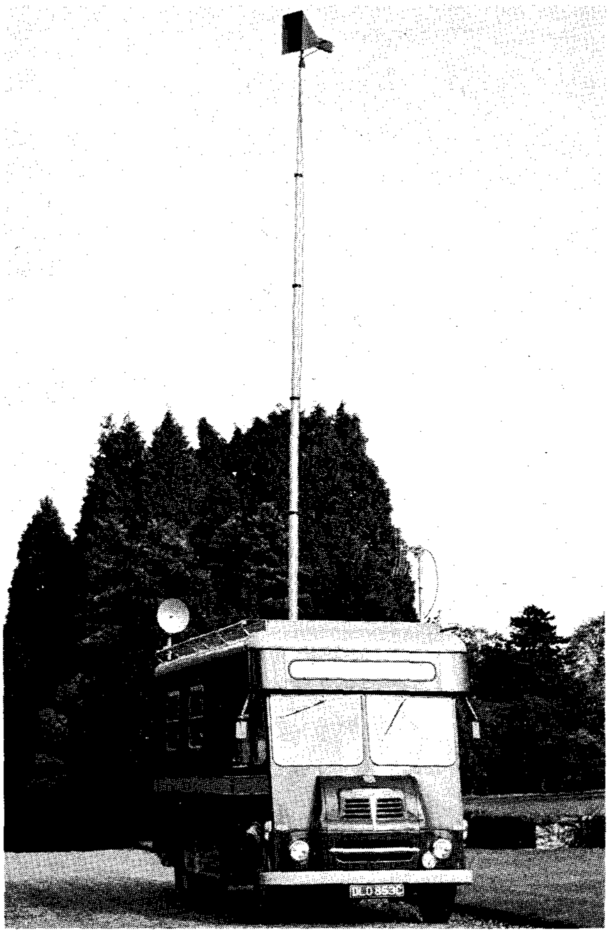

Fig. 3 - The measuring vehicle, showing the telescopic mast fully extended with the horn aerial in position

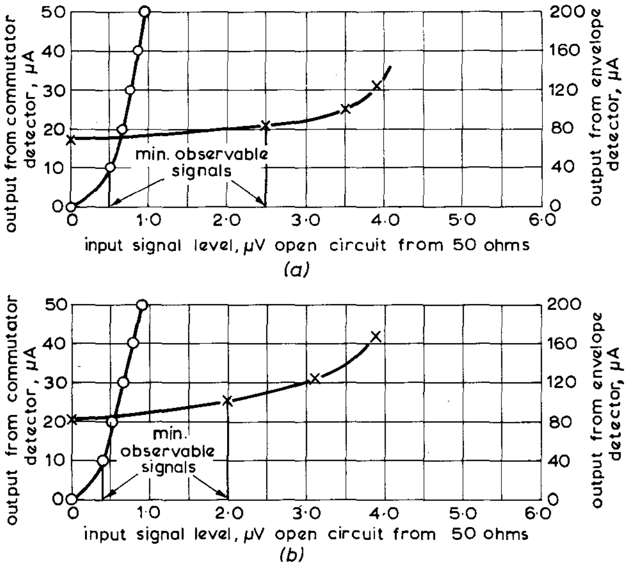

Fig. 4 - Output indication as a function of input signal level

(*a*) at 1·4 GHz
(*b*) at 1·7 GHz

x Output from envelope detector
o Output from commutator detector

3. PERFORMANCE

3.1. General

The sensitivity of the complete equipment was measured at both 1·4 GHz and 1·7 GHz in preparation for harmonic measurements which were to be made at approximately those frequencies.

3.2. The Receiver

Figs. 4(*a*) and 4(*b*) show the variation of output indication as a function of input signal level for the receiver, with and without the commutator detector, at 1·4 GHz and 1·7 GHz respectively.

The minimum measurable input signals were found in practice to be as follows:

	at 1·4 GHz	at 1·7 GHz
Using envelope detector (main receiver) only	2·5 μV	2·0 μV
Using envelope detector and commutator detector	0·5 μV	0·4 μV

These figures show that the commutator detector improved the sensitivity by 14 dB at both frequencies.

3.3. The Aerial

The aerial used with the harmonic measuring receiver comprised a rectangular brass horn with an aperture 300 mm by 450 mm. A photograph of the aerial is shown in Fig. 5. Relative to a $\lambda/2$ dipole, its intrinsic gain was 12 dB at 1·4 GHz and 14 dB at 1·7 GHz. The feeder loss was 3 dB and 4 dB respectively at the two measuring frequencies. The net gain of the aerial system was thus 9 dB at 1·4 GHz and 10 dB at 1·7 GHz.

3.4. Maximum Overall Sensitivity of Measurement

The results given in Sections 3.2 and 3.3 enable the maximum sensitivity of the overall arrangement to be specified as follows:

	at 1·4 GHz	at 1·7 GHz
Minimum measurable signal at receiver input terminals from 50 ohm source	0·5 μV	0·4 μV
Equivalent field strength assuming a half-wave dipole	7·3 μV/m 17 dB (μV/m)	7·1 μV/m 17 dB (μV/m)
Net aerial gain	9 dB	10 dB
Minimum measurable field strength (using the aerial described in Section 3.3)	2·5 μV/m 8 dB (μV/m)	2·2 μV/m 7 dB (μV/m)

3.5. Further Improvements in Sensitivity

There are three ways by which the measurement sensitivity could be further increased if required:

(i) The aerial gain could be increased by increasing its aperture; to increase the gain by 3 dB the aperture area would need to be doubled. When measuring, however, it is important to be able to explore the field over a range of aerial heights from 3 to 6 metres a.g.l. This would be less convenient if the aerial dimensions were increased above those specified in Section 3.3.

(ii) An r.f. stage could be added to the receiver. This would improve the noise factor (and hence the sensitivity) by a few decibels but, in view of the extra complication and the possible extra difficulty of tuning, it would appear not to be worthwhile.

(iii) The noise bandwidth of the receiver could be reduced at any of four parts of the receiver:

(a) Before the mixer. The tunable bandpass filter associated with the equipment has a noise bandwidth of about 30 MHz. It would not be practicable to reduce this further nor, in view of the narrower i.f. bandwidth (see below), would it be helpful except insofar that it may reduce noise or interference at the image channel response of the receiver.

(b) Before the envelope detector. The sensitivity could be increased by 10 dB if the i.f. bandwidth were decreased to 25 kHz but this would require a local oscillator having greatly increased frequency stability. The receiver would probably be less easy to tune from one harmonic to another and the general facility of measurement would be reduced.

(c) Before the commutator detector. A band-pass filter with noise bandwidth about 100 Hz was fitted between the envelope detector and the commutator detector (see Fig. 1). Because of the narrow bandwidth of the low-pass filter subsequent to the commutator detector (see below), no improvement would be obtained by further decreasing the bandwidth of this band-pass filter.

(d) Before the output meter. A low-pass filter with noise bandwidth of about 0·3 Hz was fitted between the commutator detector and the output meter. The sensitivity could be increased by further decreasing this bandwidth but the drift with time in the d.c. amplifier would then also need to be reduced. It also follows that the measurement time would be increased; this would be inconvenient when, for example, tuning the receiver or moving the aerial to explore a field pattern.

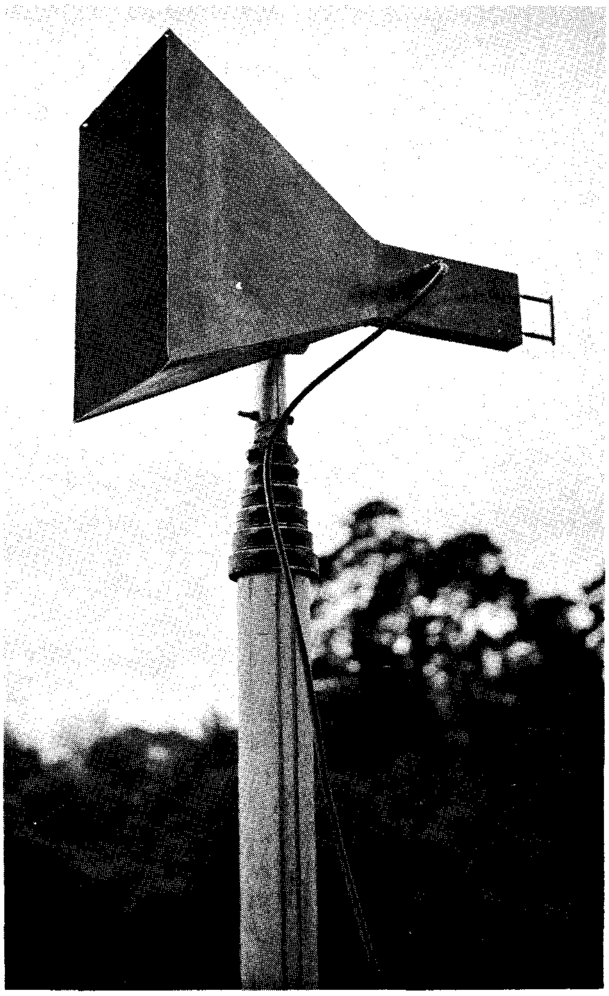

Fig. 5 - The horn aerial

It is evident that any increase of sensitivity would entail a reduction in the general facility of measurement. If, nevertheless, increased sensitivity is demanded, it would appear best to decrease the i.f. bandwidth and to accept the need for a crystal-controlled local oscillator.

4. CONCLUSIONS

The receiver described in this report enables the field strength of harmonic radiations in the frequency range 1 to 2 GHz to be measured down to about 10 dB above 1 μV/m, in the presence of fields at the fundamental frequency up to about 120 dB above 1 μV/m. It is of straightforward construction, simple to operate, and may readily be re-tuned from one harmonic to another. The aerial is reasonably small and manoeuvrable and it may be moved to explore the radiated field as a function of aerial height or position.

Experience has shown that the whole can readily be used to measure harmonic levels down to −100 dB relative to peak sync power but only in situations near to the transmitter where the fundamental field strength is large. This is a serious restriction because it can generally only be used in the sidelobe pattern of the v.r.p. of the transmitting aerial and cannot be used in the distant field. If measurements in the distant field are later shown to be necessary a more sophisticated receiver along the lines discussed in Section 3.5 will be necessary. It is evident that such a receiver would be less convenient to use and special arrangements may also be required to manoeuvre a larger aerial.

JMP

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